HIGHWAY RESEARCH REPORT

CONCRETE CREEP STUDY

INTERIM REPORT NO. 1

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STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 635148-5

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STATE OF CALIFORNIA—TRANSPORTATION AGENCY RONALD REAGAN, *Governor*

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

March, 1970

Research Report
M&R No. 635148-5
BPR No. D-3-17

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report which is the first interim report on the subproject titled:

CONCRETE CREEP STUDY

Donald L. Spellman
Principal Investigator

Jay R. Stoker and Carl R. Sundquist
Co-Investigators

Gary W. Mann and Bennett T. Squires
Project Engineers

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

REFERENCE: Spellman, D. L., Stoker, J. R., Sundquist, C. R. "Concrete Creep Study", State of California, Department of Public Works, Division of Highways, Materials and Research Department. Research Report 635148-5.

ABSTRACT: This report covers the preliminary phase of a research project to establish a rational method to calculate effects due to shrinkage and creep within structural concrete members. This initial phase consisted of checking out the new creep testing equipment; familiarizing operators and engineers with the operation of the equipment; and establishing an acceptable testing procedure.

KEY WORDS: Concrete, creep, equipment, future research, testing.

ACKNOWLEDGMENT

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This work was performed in cooperation with the U. S. Department of Transportation, Bureau of Public Roads, under agreement D-3-17.

The opinions, findings, and conclusions expressed in this report are those of the authors and are not necessarily those held by the Bureau of Public Roads.

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INTRODUCTION

Bridge construction has increased considerably this past decade with the rapid pace of building the Interstate Highway system. To facilitate the larger clearances and lane widths, as well as aesthetic and safety considerations required on modern freeways, the trend has been to longer spans with relatively low depth to span ratios. These longer spans with lower depth to span ratios are possible through the use of prestressing.

This trend has compounded the problem of accurately predicting the ultimate deflection of bridge members. The wide variation in materials and construction practices used throughout the State have further complicated this problem.

The use of prestressing in concrete bridge structures has significantly increased since its introduction within the United States in 1950. Madison County, Tennessee claims the first prestress highway structure; although a larger span, the Walnut Lane Bridge in Philadelphia, was started in 1949 but was not completed until the middle of 1951.(1)* The California Division of Highways built its first prestress structure in 1950 also, but this consisted of a pedestrian overcrossing near Pasadena. California's first prestress highway bridge, built in 1952, was a pretensioned "I" beam structure in Fresno, California. Measuring by square foot of deck area, by 1954, 5.24 percent of the bridges built in California during that year were prestressed structures. At the end of 1968 this figure stood at 37.11 percent out of a total of 10,214,141 square feet of deck area built in that year.(2)

A number of concrete bridge structures in California, whether prestressed or not, have roadway profiles deviating from design profiles as a result of variations in ultimate deflections different from those calculated. These variations are not necessarily all caused by creep, but they are accentuated by it.

Several factors contribute to variations in deflections, including the strength and modulus of elasticity of the concrete at the time the supporting forms are removed from the structure and prestressing forces or other dead loads are applied. These properties of the concrete in turn are affected by the materials, water-cement ratio, ambient temperature, the amount of moisture present during the curing period, the length of the curing period

*Numbers in parentheses refer to the list of references on Page 10.

and the density of the placed concrete. Drying shrinkage and creep of the concrete also play an important role in the ultimate deflection of the structural members. Predicting the deflection of prestressed members, is further complicated due to the increased creep factor induced by the prestressing force.

The ultimate deformation and resulting deflection can be classified into two types of deformations. These are: elastic deformation which occurs when the members are loaded, both dead load and prestressing load; and plastic deformation which continues to occur for a considerable length of time after the dead load and the prestressing forces have been applied.

Present methods used to calculate prestress losses due to elastic shortening, shrinkage and creep of steel and concrete vary a great deal. Highway structures designed by the California Division of Highways follow the recommendations of the ACI-ASCE joint committee report.[3] This committee's Method 2, the most commonly used, recommends the use of 25,000 psi total loss for post-tensioned members and 35,000 psi total loss for pretensioned members in the absence of specific loss data. The lack of specific data has been at least partially responsible for our inability to predict deflection. In order to use Method 1, values for elastic strain (ϵ_e), shrinkage strain (ϵ_s), and creep strain (ϵ_c) must be known for application within the following equation[4]:

$$\Delta f = (\epsilon_e + \epsilon_s + \epsilon_c) E_s + \delta fsi$$

Where Δf = loss in prestress
fsi = initial stress in steel
E_s = modulus of elasticity of steel
δ = ratio of relaxation loss to the initial prestress force in steel

and ϵ_e, ϵ_s, and ϵ_c are as noted above.

The ultimate objective of this project, therefore, will be to determine shrinkage and creep characteristics for several material sources throughout the State; and an effort will be made to establish a more rational basis to calculate losses due to these factors within structural concrete members. This would be a benefit to engineers in design, as well as construction engineers for camber determinations.

This initial report covers the work accomplished in Phase 1 of a three phase project. This phase has consisted of familiarizing operators and engineers with the operation of the newly acquired creep testing equipment and to establish an acceptable testing procedure.

EQUIPMENT DEVELOPMENT

The University of California at Berkeley has for some time been involved with concrete creep investigations. Initially begun in 1925 by Professor Raymond E. Davis, the first test specimens were all spring loaded. To use springs in maintaining a constant load, great care is required in applying the initial load, and numerous manual adjustments are required in sustaining the load over a long period of time. In more recent studies, the need for equipment to simplify the load applications and service maintenance has resulted in their development of a reliable hydraulic system. This consists of a hydraulic cell for load application in conjunction with an electronically controlled pressure supply system.

The Division of Highways, therefore, was able to duplicate with few alterations a system already proven resulting in a considerable savings in initial test equipment development. A detailed description of the University of California's equipment and development is given by C. H. Best, D. Pirtz, and M. Polivka in "A Loading System for Creep Studies of Concrete."(5)

Briefly, the system consists of a shallow steel cylinder with a molded rubber seal and a piston with a steel plate on top for load application. As suggested in reference 5, our loading cells were improved by providing a method for collecting the small amount of oil that seeps by the rubber seal. This was

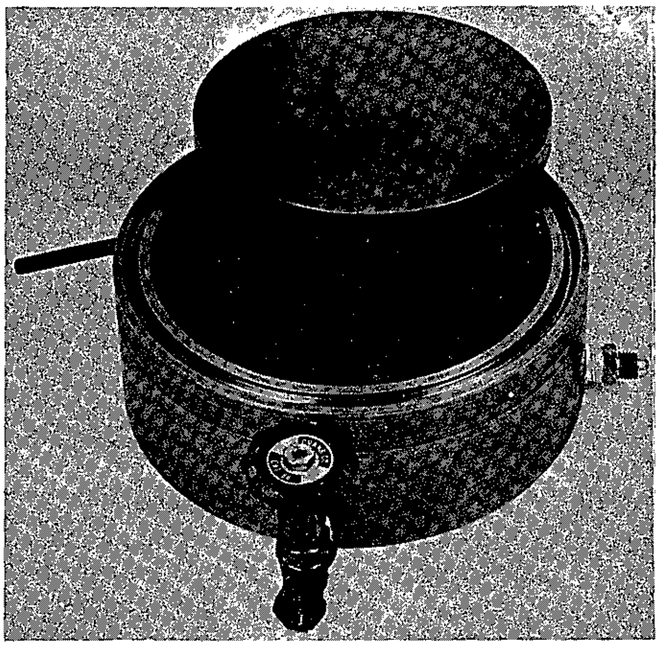

Figure 1

Loading Cell for Concrete Cylinders

accomplished by grooving the top of the steel cylinder and machining an opening fitted with a small length of copper tubing to drain. This small amount of leakage is believed to be beneficial by the equipment designers in preventing the rubber piston from freezing in the cylinder.

The pressure is supplied to the system by an American Bosch diesel fuel-injection pump driven by a 3/8 h.p. electric motor. This pump is capable of relatively high pressures with low displacement. A larger displacement manually operated pump was added to our system to reduce the time required to load the test cylinders initially. After approaching the desired pressure, the manual pump is shut off from the system and the electronic pressure regulator is activated to bring the loading cell to the final sustained stress with the injector pump. The pressure regulator, sensitive to small decreases in line pressures of about 1%, then maintains the desired pressure. A nitrogen filled hydraulic accumulator is also included in the system. This device has a diaphragm with gas on one side at a pressure of 700 psi and connected on the other side to the fluid pressure system. Should any power or regulator failure occur, the accumulator prevents any substantial loss in pressure until necessary repairs are made. Although the injector pump has a very small displacement, the accumulator also insures against surging or shocks by acting as a surge tank.

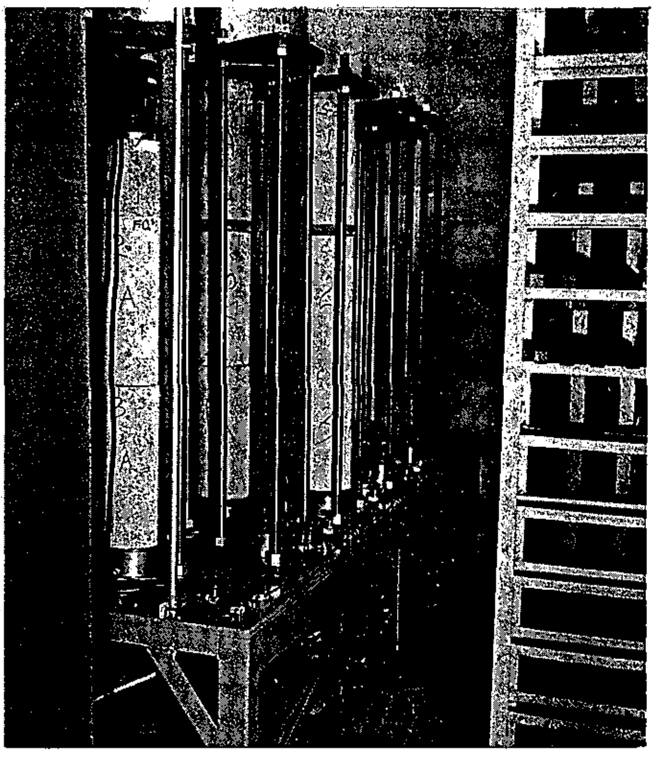

Figure 2

Loading Racks - Hydraulic Pressure Apparatus Beneath Table

Appendix A is a detailed procedure for operating the creep testing equipment.

Nine stacks of three specimens each can be accommodated simultaneously in our equipment. The hydraulic pressure (maximum 3,000 psi) is kept constant at the preset level by a Honeywell automatic regulator. Figure 2 is a photograph of the loading racks which are located in a temperature and humidity controlled room.

DISCUSSION

The apparatus was completed in October 1968, and was installed in the drying room of the concrete laboratory. The drying room complies with the requirements of ASTM Designation: C-157.

Preliminary testing began with several creep cylinder specimens which were fabricated from stock laboratory materials. The creep cylinders are 16" high and 6" in diameter and are fabricated in steel forms. The concrete creep specimens have three sets of gauge pins placed 10 inches apart vertically and at intervals of 120° around the circumference. This 10-inch gage length with three inches of concrete between the pins and specimen ends eliminates some of the variation caused by end reactions. The three evenly spaced measuring lines are required to eliminate the effects from any eccentricity of the loading of the concrete specimens. A stack of three such cylinders comprise one "creep test". In addition to the creep specimens, three identical cylinders fabricated from the same concrete mix as the creep specimens are used for determining the drying shrinkage of the concrete. These drying shrinkage specimens are stacked three high in racks adjacent to the creep equipment in the drying room.

Mechanically and hydraulically the creep test equipment has performed very well in our preliminary testing program, with only a few minor alterations required. Bleeder valves were added to facilitate the return of the pistons to the zero position after a test. The steel form molds for the test cylinders were originally fabricated as gang molds to accommodate three specimens each. Due to the excessive weight of this system, the molds were divided to form individual molds to facilitate the movement of specimens after fabrication. Three months of experimentation were necessary to develop a procedure to obtain a test on a stack of specimens that met all the desired creep test criteria. To aid others who may become involved in similar testing, the problems that we experienced are discussed below.

Initially, creep measurements, which are made on three sides of each of three cylindrical specimens in a stack, had too much variation. Specifications used for Bay Area Rapid Transit District construction control, which were used as a guide for our work, state that on any one specimen the creep readings on any single side must be within 25% of the average of all three creep readings for that specimen. In early testing, readings were so poor that in at least one case an expansion reading was measured on one side while compression readings were noted on the other two sides. Our initial conclusion was that the sulfur capping compound was providing varying surfaces not normal to the vertical axis of the cylinder. These conditions did in fact exist, but not with the same degree of irregularity on each end of each specimen. Our first attempt to solve the problem involved adjusting the upper bearing plate of the equipment so that it was normal to the stack of concrete cylinders. We did not try to perfectly normalize the orientation of the platens on each end of the specimens, but by the use of leveling screws on the equipment, we tried to make the upper plate bear perfectly on the top cap of the top cylinder in the stack. We felt that since the bottom bearing plate was a hydraulic piston free to pivot on its hydraulic fluid the stack would take the position such that uniform loading through the concrete from bottom to top would occur. Measurements, however, disclosed no improvement. Next we eliminated capping the smooth bottom or molded end of each specimen, using capping compound only on the relatively rough finished top end. The stack still failed to stand perfectly straight and uniform creep criteria were still not met.

All test criteria were met for the first time when the specimens were prepared, using the following procedure: The creep specimen molds were filled 1/8" to 1/4" short of the top and allowed to set about one hour. This enabled the bleeding and further consolidation to occur prior to the final finishing of the top. The unfilled portion was later filled with neat cement and finished very carefully with a glass plate to make the end as normal to the cylindrical axis as the concrete molds were machined. A target circle was machined into the upper header

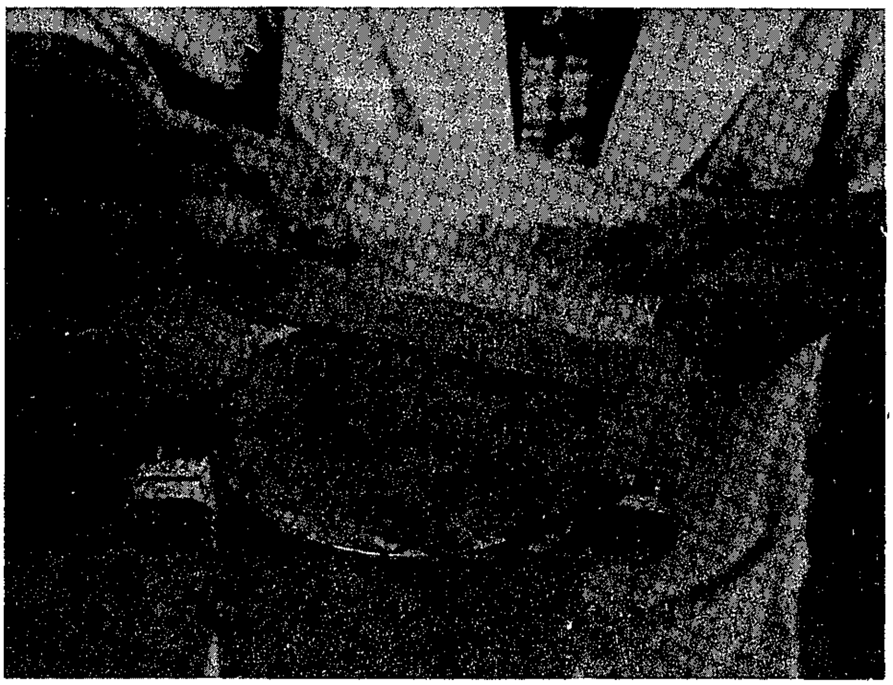

Figure 3

Final Finishing of Cement Paste Used on Top of Creep Specimens plates to insure that the upper and lower cylinders in the stack were in the same relative positions in the testing apparatus. The stack of cylinders were placed squarely on the piston base and in the target circle on the upper plate which made the vertical axis of the cylinders parallel to the upright bars. A spacing bar was used to insure that the upper and lower plates were parallel. The stack was held firmly in the described position until the load was applied and firm contact made top and bottom. This method was adopted for all future testing.

Figure 4

Spacing Bar Being Used to Insure That Upper Plate is Parallel to Lower Plate

PROPOSED WORK

This project has been planned as a three phase study. The work of phase two and three is dependent upon information obtained in the preceding phase.

Phase 1 - Complete (This Report)

This phase consisted of checking the performance, and familiarizing researchers with the use of the creep testing equipment. This was accomplished during the past fiscal year. The Bay Area Rapid Transit Authority specification was used as a guide for the testing of the equipment. The complete specification is shown in Appendix B.

Phase 2

This phase will consist of evaluating shrinkage and creep characteristics of concrete using various aggregate sources, ages at loading, water-cement ratios, curing conditions, and other variables that appear to affect ultimate deflections of bridge members under field conditions.

The necessary information for computer reduction of the creep readings has been forwarded to our electronic data processing personnel. Preparation and refinement of a computer program will be accomplished during Phase 2 of this project.

Phase 3

Phase 3 will consist of developing criteria to be used in design and in specifications regarding the creep and shrinkage properties of concrete using various California aggregates and other variables such as environment. The study of these variables will require the establishment of testing procedures which measure the effect of each variable on creep of concrete. If possible, a chart or nomograph to aid in design of concrete members will be developed as a portion of this phase.

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(5) Best, C. H., Pirtz, D., and Polivka, M.,
"A Loading System For Creep Studies of Concrete",
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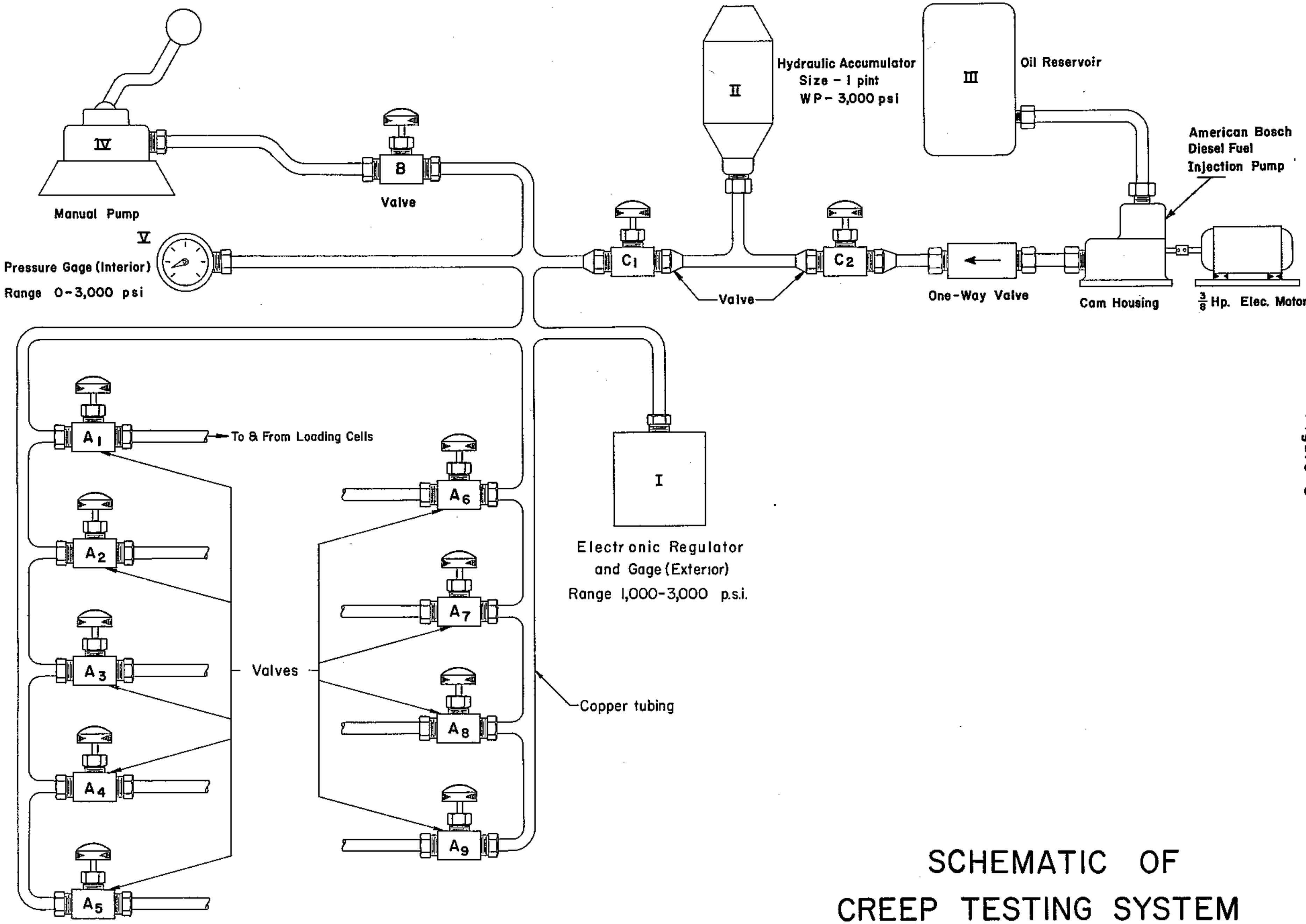
Figure 5



SCHEMATIC OF
CREEP TESTING SYSTEM

APPENDIX A

PROCEDURE FOR USE OF CREEP TESTING EQUIPMENT

PART A

Steps to follow in placing cylinders in loading racks when no pressure is on the system.

1. Check switch that activates the Honeywell electronic regulator. It should be placed in the "off" position (gage outside drying room).

2. Valves (C_1, C_2) on each side of the hydraulic accumulator (II) should be closed. Check! (See Figure 5)

3. Fill oil reserve tank (III) to within a few inches of top to insure adequate supply of fluid. (Use S.A.E. 10 motor oil)

4. Open all valves (Ai) to loading cells that are to be used. Close all valves on unused cells.

5. Place concrete specimens to be tested in position and align top and bottom plates parallel with the spacing bar. (See Figure 4)

6. Turn valve (B) to the open position adding manual pump (IV) to system. (Valve is open when handle is in line with copper tubing - closed when turned 90°)

7. With manual pump, bring pressure to within 100 ± psi of the desired operating pressure by use of pressure gage (V). Close valve (B). Dump pressure in pump by turning small lever on side of pump down.

8. At this point, check pressure gage (V) to be sure pressure is not dropping. If visual decrease in pressure is noted, check for leaks around loading cells, bleeding valve on loading cells, copper fitting, etc.

9. Pressure in the hydraulic accumulator is 700 psi. Therefore, valves (C_1, C_2) cannot be opened unless the pressure within the system as recorded on pressure gage (V) is above this figure; preferably the pressure should be about 1000 ± psi. If the line pressure is adequate, the valves (C_1, C_2) are opened placing the accumulator and the injector pump in the system. (A slight change in pressure will occur at this point.)

10. The Honeywell electronic regulator is now activated and the small injector pump will bring the pressure to the preset desired pressure. Check when pump stops for final pressure.

PART B

<u>Steps to follow when placing additional cylinders in loading rack with pressure on the system</u>

1. Turn the Honeywell electronic regulator off.

2. Close the valves (C_1, C_2) on each side of the hydraulic accumulator.

3. Close the valves (Ai) leading to the loading cells already in use. This will keep the pressure on the specimens until the system is reopened. (Avoid leaving the pump off for more than an hour).

4. Turn the small lever on the side of the manual pump up, then turn valve (B) to the open position. Pressure can now be bled off slowly by lowering lever back down.

5. The valves (Ai) of the loading cells to be placed in the system can now be turned to the open position.

6. Follow steps 5, 7, 8, and 9 in Part A.

7. Activate the Honeywell electronic regulator and pump. As the injector pump brings the pressure to within 10-20 psi of the pressure on the closed off racks, open their valves.

APPENDIX B

Test Method No. BART 2
(November 1, 1965)

METHOD OF TEST FOR DETERMINING THE CREEP OF A TEST CONCRETE MIX IN COMPRESSION

1.0 SCOPE

This test method is intended to provide a standardized procedure for determining the compressive strength, static modulus of elasticity, and compressive creep of a test concrete mix in comparison to that of a reference concrete mix.

2.0 GENERAL

The provisions of ASTM Designation: C512, TENTATIVE METHOD OF TEST FOR CREEP OF CONCRETE IN COMPRESSION, shall apply except as modified and supplemented herein.

3.0 APPARATUS

3.1 Molds

A. Molds for compressive strength and static modulus of elasticity specimens shall be 6 inches in diameter by 12 inches in height conforming to ASTM Designation: C192.

B. Molds for compressive creep specimens and their corresponding drying shrinkage specimens shall be 6 inches in diameter by 16 inches in height conforming to ASTM Designation: C192. If external measuring devices are used, brass inserts, at least 7/8 inch in length, tapped to receive stainless steel contact seats, shall be secured in the mold.

The inserts shall be held in such a manner that they may be released from contact with the mold before the mold is removed from the specimen. When assembled to receive concrete, the mold shall be substantially watertight, and its axis perpendicular to the baseplate.

C. The interior surfaces of the molds shall be coated with a release agent. A satisfactory substitute can be made by mixing a 12 percent solution, by weight, of white paraffin and a low aniline petroleum solvent of the intermediate grade. After the molds have been coated, the gauge studs shall be placed in the end plates. Care shall be taken to keep the studs free from release agent.

3.2 Loading Frame. It is recommended that the compressive creep specimens are not stacked during testing. It is further recommended that the specimens be loaded with hydraulic loading capsules that are connected to a source of high pressure through an individual valve and a pressure regulating device consisting of an accumulator, a regulator and an indicating gauge.

3.3 Strain-Measuring Device. If external strain-measuring devices are used, strain shall be measured on three gauge lines at 120 degree centers. The effective gauge length shall be 10 inches plus or minus 0.10 inch and shall be centered on the specimen. A length comparator conforming to the requirements of ASTM Designation: C490 is a suitable external strain-measuring device.

3.4 Other Apparatus. Other concrete testing apparatus, as required, shall conform to the requirements of ASTM Designation: C157 except as modified and supplemented herein.

A. Atomometer. It is recommended that the atomometer defined in ASTM Designation: C157 be revised to include an adjustable torque handle. If this recommendation is followed, the filter paper shall be mounted on the atomometer and shall be secured in place while dry by turning of the torque handle until it just starts to slip.

B. Filter Paper. E and D filter paper No. 652 manufactured by Eaton-Dikeman Company, Mt. Holly Springs, Pennsylvania complies with these requirements.

4.0 CONCRETE MATERIALS

4.1 General. The provisions in Section 90, PORTLAND CEMENT CONCRETE, of the Standard Specifications shall apply except as modified and supplemented herein.

4.2 Cement. The cement used in the reference mix shall be composed of a mixture of equal parts produced by the following mills.

Permanente Cement Company
Permanente, California

Calaveras Cement Company
San Andreas, California

Santa Cruz Cement Company
Davenport, California

4.3 Aggregate. The sand and coarse aggregate used in the reference mix shall be produced by Joe Chevreaux from the Bear River in the vicinity of Auburn, California.

The grading limits of the combined aggregate in the reference mix shall be in accordance with the following requirements:

Sieve Size	Percent Passing
1-1/2 inch	100
3/4 inch	88 - 93
3/8 inch	60 - 65
No. 4	46 - 52
No. 8	35 - 39
No. 16	27 - 30
No. 30	18 - 21
No. 50	6 - 8

4.4 Admixtures. No admixtures shall be used in the reference mix.

5.0 TEST SPECIMENS

The compressive strength and static modulus of elasticity specimens shall be 6-by-12-inch cylinders. The compressive creep and drying shrinkage cylinders shall be 6-by-16-inch cylinders.

6.0 NUMBER OF SPECIMENS

At least three specimens shall be prepared for each test condition. One batch of the reference concrete, one batch of the test concrete without admixtures, and (if admixtures are proposed) one batch containing the maximum dosage of the admixture as recommended by the manufacturers, shall be mixed consecutively.

6.1 Complete Test Program Requirements. The complete test program will produce the following specimens:

A. Reference Concrete Mix Specimens

12) 6-by-12-inch cylinders
6) 6-by-16-inch cylinders

B. Test Concrete Mix Specimens (without admixtures)

12) 6-by-12-inch cylinders
6) 6-by-16-inch cylinders

C. Additional Test Concrete Mix Specimens (when admixtures are used)

12) 6-by-12-inch cylinders
6) 6-by-16-inch cylinders

7.0 MIXING CONCRETE

The provisions of ASTM Designation: C157 shall apply except as modified or supplemented herein.

7.1 Batch Size. The concrete shall be mixed in batches of not less than 2.0 cubic feet but not less than 50 percent nor more than 100 percent of the rated capacity of the mixer. If all of the specimens are not molded from the same batch, the 6-by-12-inch cylinders shall be molded from a single batch and the 6-by-16-inch cylinders shall be molded from a single batch.

7.2 Mortar Retention. The mixer shall be "buttered". "Over-mortaring" shall not be allowed.

7.3 Cement Factor. The cement factors of the reference and test mixes shall vary not more than plus or minus 0.1 sack per cubic yard from that specified for the class of special concrete being tested.

7.4 Water Content. Sufficient water shall be added to produce a Kelly Ball penetration of 1-3/4 plus or minus 1/4 inches.

7.5 Concrete Temperature. The temperature of the mixing water shall be adjusted so that the temperature of the freshly mixed concrete is 73 plus or minus 3 degrees Fahrenheit.

8.0 CONCRETE PROPERTIES

8.1 Workability. After mixing, the Kelly Ball penetration shall be measured in accordance with the provisions of ASTM Designation: C360, STANDARD METHOD OF TEST FOR BALL PENETRATION IN FRESH PORTLAND CEMENT CONCRETE. If the penetration is less than 1-1/2 inches, the concrete shall be returned to the mixer, water shall be added, and the batch shall be remixed for not more than one minute. The Kelly Ball penetration shall be remeasured after adjusting the water content.

8.2 Unit Weight and Cement Factor. The unit weight in pounds per cubic foot and the cement factor in sacks per cubic yard shall be determined in accordance with the provisions of ASTM Designation: C138, STANDARD METHOD OF TEST FOR WEIGHT PER CUBIC FOOT, YIELD, AND AIR CONTENT (GRAVIMETRIC) OF CONCRETE.

8.3 Air Content. The air content of stone aggregate concrete shall be determined in accordance with the provisions of ASTM Designation: C231, STANDARD METHOD OF TEST FOR AIR CONTENT OF FRESHLY MIXED CONCRETE BY THE PRESSURE METHOD. After all of the concrete property tests of Article 8.0 have been completed, the surplus water from the surface of the concrete in the air meter shall be taken up with a sponge. All concrete shall be returned to the mixer and remixed for not more than one minute.

The air content of lightweight aggregate concrete shall be determined in accordance with the provisions of ASTM Designation: C138.

9.0 MOLDING SPECIMENS

The provisions of ASTM Designation: C192 shall apply except as modified or supplemented herein.

9.1 Compressive Creep and Drying Shrinkage Specimens. The 6-by-16-inch cylinders shall be molded before the 6-by-12-inch cylinders. The concrete shall be placed in layers each about 4 inches in depth. Each layer shall be rodded with 25 strokes of the rod, with care taken not to strike the brass inserts. Immediately after molding, the brass inserts shall be released from the mold.

10.0 CURING OF SPECIMENS

10.1 Test Concrete. The curing method for the test mix shall be as proposed for the special concrete and shall be in accordance with the requirements of Section 51 of the Standard Specifications and these special provisions. For moist curing methods, the surrounding room temperature shall be maintained between 70 and 76 degrees Fahrenheit.

10.2 Reference Concrete. The reference mix shall be cured for seven days in a fog room maintaining a relative humidity of 90 percent or greater and a temperature of 73.4 plus or minus 3 degrees Fahrenheit.

10.3 Removal of Molds. The specimens shall be removed from the molds after 24 plus or minus 4 hours, or at the end of the curing period, whichever is first.

11.0 STORING SPECIMENS

After the curing period, the specimens shall be stored in air of nominal room temperature and humidity. The stored specimens shall not be exposed to direct sunlight. Storage facilities shall be provided to allow free air circulation on all specimen surfaces except the capped ends. After the compressive creep and drying shrinkage specimens have reached the age of "dry age 0 days" (defined in Article 12.1), they shall be stored in air as defined in paragraph 4 of ASTM Designation: C512 until completion of the test.

12.0 TESTING SPECIMENS

12.1 Dry Age 0 Days. The specimens shall be tested when they have reached "dry age 0 days". This condition represents one of the following:

A. Prestressed Concrete - proposed age at load transfer

B. Reinforced Concrete - proposed age at stripping of supporting formwork.

12.2 Compressive Strength and Static Modulus of Elasticity. The 6-by-12-inch cylinders from each batch shall be tested for compressive strength at the following ages:

A. Dry age 0 days
B. Dry age 14 days
C. Dry age 28 days
D. Total age 28 days
(Total ages will vary with method of curing)

During each loading, determine the static modulus of elasticity in conformance with ASTM Designation: C469.

Additional compressive strength cylinders may be required to determine "dry age 0 days". These cylinders need not be tested for static modulus of elasticity.

12.3 Compressive Creep and Drying Shrinkage. Three of the 6-by-16-inch cylinders from each batch shall be tested for compressive creep. The remaining three 6-by-16-inch cylinders from each batch shall be tested for drying shrinkage.

The initial length along each gauge line shall be determined before the compressive creep specimens are loaded. A load of 1200 pounds per square inch shall be applied to the compressive creep specimens and maintained constant throughout the test period. As soon as the load has been applied, measurements shall be made along the gauge lines. This measurement represents "dry age 0 days". Deformations along the gauge lines of all specimens shall be measured at dry ages of 7, 14, 21 and 28 days.

12.4 Procedure for Determining Deformation by Means of External Measuring Devices. With the strain gauge in position on the reference bar, the dial shall be set to zero and the reading recorded. The bar shall be in a vertical position. Next, each gauge line on a specimen shall be measured. The gauge on the reference bar shall be checked and the second specimen shall be measured. After all specimens to be tested at this time have been measured, the schedule of measurements shall be repeated. If there is any discrepancy greater than one dial division between original and repeat measurements, the measurements shall be repeated again until checks within one dial division are obtained.

12.5 Procedure for Preloading Creep Specimens. The preload shall not exceed 400 pounds per square inch. A reasonable deformation variation for this load is one dial division (0.0001 inch). If preloading is employed and the specimen is unloaded and readjusted in the frame, a new initial length shall be determined before reloading. Although there is no requirement for deformation compatibility at the preload, the requirements of Article 13.1 shall apply to all other measurements and compliance with the provisions of this article shall not provide relief from the requirements of Article 13.1.

13.0 CALCULATIONS

13.1 Average Deformation. The deformation of each specimen along each gauge line shall be computed as the difference between the initial length (at "dry age 0 days") and the length after drying at each test age. The deformation of each specimen at each test age shall be computed as the average of the three gauge line deformations. If the measured deformation along any gauge line departs from the average deformation of the specimen by more than 25 percent at any test age, that specimen shall be considered to be not acceptable and the results shall not be used in subsequent calculations.

13.2 Average Strain. The average deformation of the specimens of the reference mix and each test mix shall be computed to the nearest 0.00001 inch at each test age. If the deformation of any specimen departs from the average for that test age by more than 0.0004 inch, the results obtained from that specimen shall be discarded. If less than 3 shrinkage and 3 creep specimens remain, additional rounds shall be made. The average of the specimens shall be expressed as a deformation per unit length (strain) to the nearest 0.000001 per inch.

13.3 Creep Plus Elastic Strain. The average strain of the drying shrinkage specimens shall be subtracted from the average strain of the creep specimens at each test age. The results shall be recorded as creep plus elastic strain at each test age.

13.4 <u>Graphical Representation</u>. The average creep plus elastic strain of the reference concrete mix and the test concrete mix shall be plotted against t + 1, where t equals the dry age in days at each test age. The plot shall be made on semi-log paper, with t + 1 plotted on the log scale.

The results shall be represented by the equation

$$(C + E) = m \log (t + 1) + b$$

Where: C = creep strain
E = elastic strain
t = dry age in days
b and m = constants

13.4.1 The constants b and m shall be determined by solving the following equations simultaneously

$$\Sigma\left[(C + E) \log (t+1)\right] = \Sigma\left[\log (t + 1)\right]^2 m + \Sigma\left[\log (t+1)\right] b$$

$$\Sigma (C + E) = \Sigma\left[\log (t + 1)\right] m + n b$$

Where: (C + E) = observed strains (average at each test age)
n = number of observations (test ages)

(Solution of these equations may result in problems of significant figures. Satisfactory solutions may be obtained using six place logarithms and assuming that the observed strains are accurate to the nearest millionth of an inch per inch.)

13.4.2 The straight line represented by the equation above shall be plotted on the semi-log paper and the creep plus elastic strain value of the equation shall be computed at a dry age of 28 days. The 28 day creep strain shall be taken as the 28 day creep plus elastic strain less the value of the constant b. (The observed strain at dry age 0 days shall be disregarded.)

13.5 <u>Compressive Creep Comparison</u>. The 28 day creep strain of the test concrete mix shall be divided by that of the reference concrete mix and multiplied by 100. The calculation shall be carried to the nearest 0.1 percent and rounded off to the nearest unit of percentage, with values ending in 0.5 counted as the next smaller whole number.